

## MEASUREMENT OF THICKNESSES OF STEEL

W.F. Schmidt  
Department of Mechanical Engineering  
University of Arkansas  
Fayetteville AR 72701

O.H. Zinke  
International Validators, Inc.  
817 North Jackson  
Fayetteville AR 72701

## INTRODUCTION

The standard 55-gallon barrel is frequently used for storage of hazardous chemicals and low-level radioactive materials. Corrosion on the inner surface of the barrels produced by the stored materials may produce wall thinning. Wall thinning may be a problem either in long-term storage or where the barrels must be moved. Ultrasonics could determine the degree this thinning, but the nature of the stored material may discourage the use of the couplant associated with ultrasonics. Electromagnetic fields suggest a way to detect wall thinning rapidly and without the use of couplant.

AC magnetics is a convenient way to use electromagnetic fields to measure real and imaginary reluctances of ferrous and nonferrous metals at relatively large values of lift off (distance between sensor and sample) and at the low frequencies appropriate to the skin-depth of steel. Both of these reluctances are responsive to material thickness. However, there are two problems which could produce spurious variations of reluctances of a magnitude which might mask detection of material loss in the walls of commercial barrels. One problem is the variation of the paint thickness on the surface of 55-gallon barrels. This is a lift-off problem since electromagnetic fields are usually not responsive to paint. Both reluctances are shown here to be responsive to lift off. The second problem is the effect on both reluctances of variations of steel quality.

It will be shown here that because of a unique quality of the lift-off versus thickness behavior in the complex-reluctance plane, the imaginary reluctance can be used to correct for lift off variations. When lift-off effects are eliminated, the variability in the real reluctance associated with steel quality will be seen to be so small that it does not mask detection of the very small changes in wall thickness tested here.

## THE EXPERIMENT

The rounded surface of a new 55-gallon barrel was cut into eight approximately equal segments. The segments were approximately 44 cms long in the circumferential direction and 37 cms long in the direction of the height of the barrel. The normal

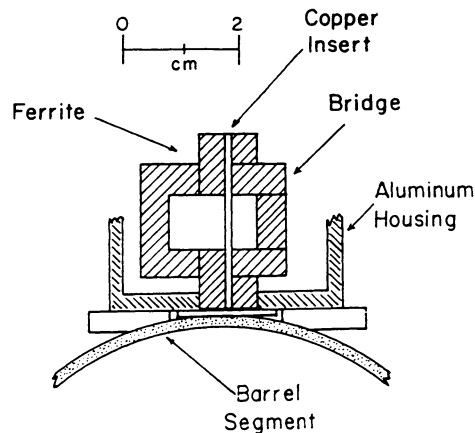


Fig. 1. Schematic of position of ac magnetic bridge on barrel segment.

thickness of the segments with paint was 0.8 mm. Two of these segments were scanned on the painted surface with ac magnetics [1,2,3] at 500 Hertz for a distance of about 30 cms in the circumferential direction. The real and imaginary reluctances were recorded for 0.5-cm intervals. Since the wall thickness was not altered for these scans, they are called "control" scans. Two control scans were carried out on one segment and one on the second segment.

For all scans, the bridge was positioned as shown in Fig. 1. In Fig. 1 the curvature of the barrel surface is exaggerated. A 0.25-mm piece of plastic was placed between the gap of the bridge and the painted surface of the barrel. This center segment was flanked on each side by a thicker plastic which was ground to conform to the barrel surface as shown in the figure.

The scans were carried out with an ac magnetic bridge with geometry similar to that shown in Fig. 2 of reference [4]. The copper insert shown in Fig. 1 flanked by the two ferrite bridge halves simultaneously shields the input from the output of the bridge and effectively pushes the magnetic field out of the gap. This insert is also responsible for the

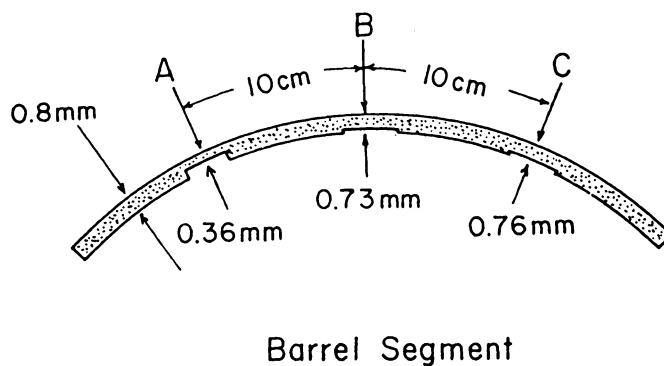


Fig. 2. Cross section of etched segment of the barrel.

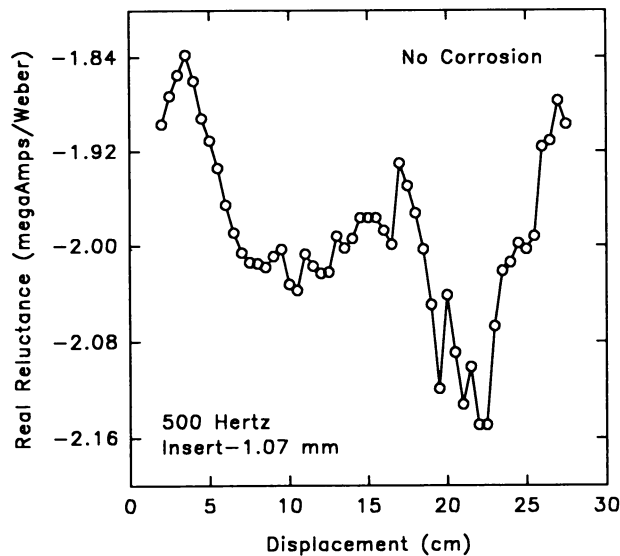


Fig. 3. Real reluctance (control) scan across unetched barrel segment.

pole configuration which produces independently measured values of real and imaginary reluctance [3]. The insert was 1.07-mm thick. The bridge was operated at an input Amp-turns of 20.

After the control scans were completed, three spots were etched as schematized in Fig. 2 with hydrochloric acid below one of the control scans. The etched spots are labeled A, B and C, and the wall thicknesses at the etches were measured to be 0.36, 0.73 and 0.76 mm respectively. The etched spots were approximately 3 cm in diameter and were spaced about 10 cm apart as shown.

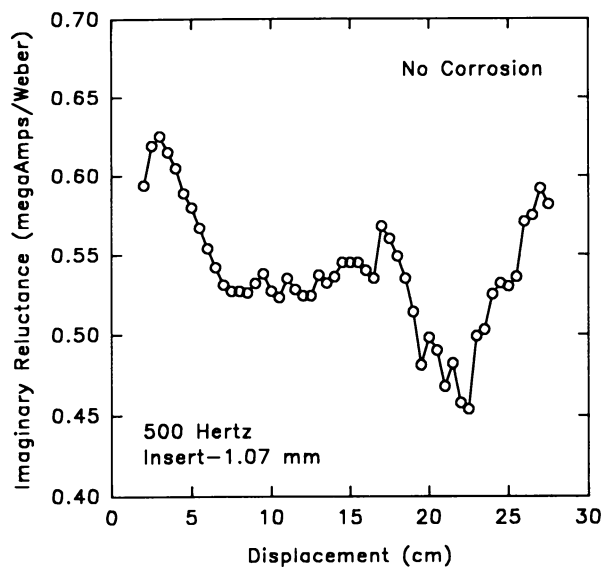


Fig. 4. Imaginary reluctance (control) scan across unetched barrel segment.

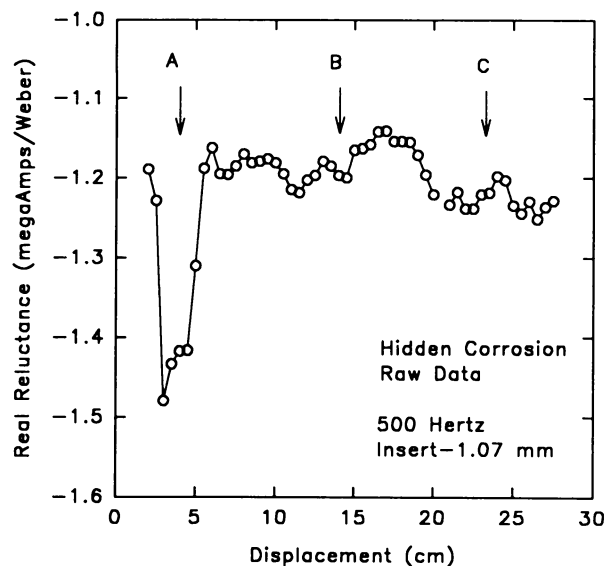


Fig. 5. Real reluctance scan across etched barrel segment.

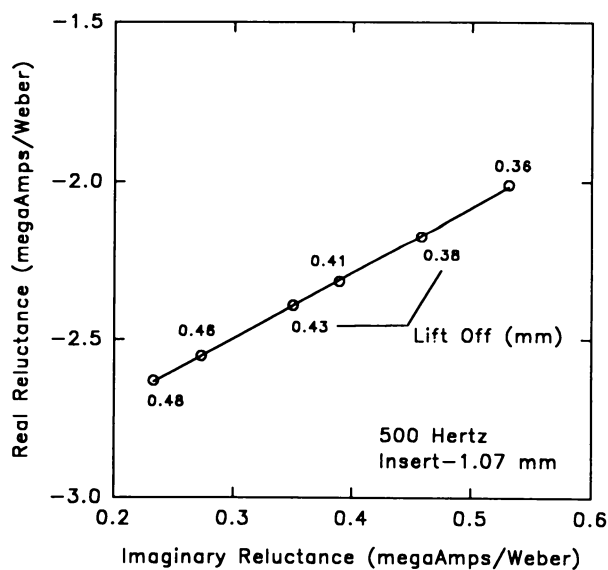


Fig. 6. Lift-off variations of real and imaginary reluctance in the complex-reluctance plane.

The real ( $R_m$ ) and imaginary ( $I_m$ ) reluctances typical of any of the control scans are shown in Figs. 3 and 4. The other two control scans showed features of similar magnitude and width except at different values of the displacement. The real reluctance variations across the etched scan is shown in Fig. 5. The letters A, B, and C indicate the central positions of the respective, etched areas.

In addition to these measurements, the variation of real and imaginary reluctance with lift off was measured at 14 cm along the scan. Lift off was varied between 0.36 and 0.48 mm from the painted surface of the barrel. The results are displayed in the complex-reluctance plane in Fig. 6. The straight line in this figure is a mean-squares fit with the equation of the line

$$R_e = -3.12 + 2.078 I_m. \quad (1)$$

#### TYPICAL COMPLEX RELUCTANCE PLANES FOR STEELS

In a separate experiment, the variations of real and imaginary reluctances were measured for 1010-steel samples of various thicknesses. Lift off, frequencies and insert widths were also varied. The samples here were metal foils 15 by 15 cm. A typical complex-reluctance plane for an insert thickness of 1.63 mm at 100 Hertz is shown in Fig. 7. The relation between the constant thickness and constant lift-off lines varied depending on the frequency and the insert thickness. However, the behavior seen in Fig. 7 is fairly typical of the most of the data. The striking aspect of that behavior is that the lines of constant imaginary reluctance and real reluctance are essentially at right angles to each other. Constant imaginary reluctance and real reluctance are essentially at right angles to each other. Also, particularly at the smaller values of lift off, the real reluctance at constant sample-thickness does not change appreciably with lift off while the imaginary reluctance at constant lift off changes very little with sample-thickness.

#### REMOVAL OF LIFT-OFF EFFECTS

These observations and those shown in Fig. 6 gave rise to a procedure to remove the effects of lift off from the real- reluctance scans. The imaginary reluctance shown in Fig. 4, for example, was substituted into the above equation and the real reluctance thus calculated was subtracted from the real reluctance of Fig. 3. When this process is carried out, the effects of lift off should be eliminated and the remaining variations of real

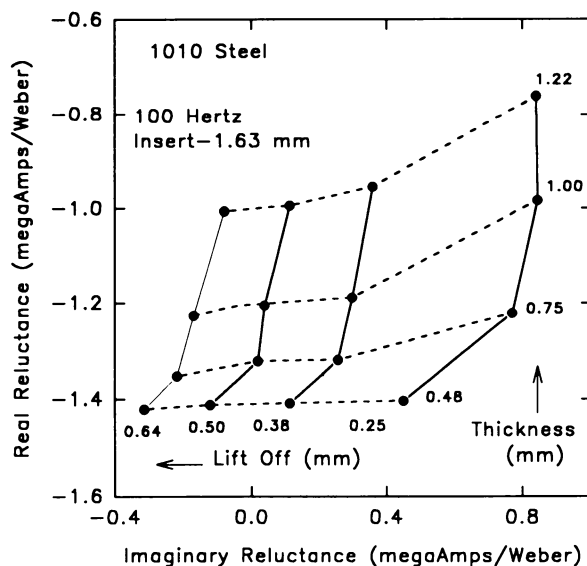


Fig. 7. Complex-reluctance plane representation of sample thickness versus lift off for 1010 steel.

reluctance with displacement should be solely a result of the variations of the quality of the steel. The results of this calculation are seen in Fig. 8, where the fluctuations are much smaller than those of Fig. 3. Since lift-off effects have been removed, the variations seen in Fig. 8 must then result from metal quality. It will be seen that these effects can be ignored when compared to actual metal losses of the order of 5%. The three spikes seen in this figure may or may not represent a real effect. The reproducibility of a data point in Fig. 8 is about the size of the data circles.

The scheme for inspecting standard 55-gallon barrels with ac magnetics then becomes a simple process. Measure the real and imaginary reluctances in circumferential scans of the areas of the barrel. Determine the above equation for the barrel. Substitute the imaginary reluctance into the lift-off equation to calculate the real-reluctance variations with lift off. Finally, subtract this calculated real reluctance from the measured real reluctance and the results should indicate the presence of corrosion loss, if any.

This was the exact process carried out for the segment of a barrel surface schematized in Fig. 2. The results are displayed in Fig. 9 and can be compared to the raw data in Fig. 5. The locations of the three etched areas corresponding to the etched areas A, B, and C are indicated on Fig. 9. Reluctance variations from all three etched areas appear in Fig. 9, which is surprising because so little wall loss occurred for B and C.

Assuming linear response of the real reluctance and using the real reluctance at A as a reference, the loss at B calculates to about 7 percent of thickness of the barrel. From the micrometer measurements, the loss was about 9 percent. This agreement is well within the tenuous accuracy of the micrometer measurement.

## CONCLUSIONS

The imaginary-reluctance patterns produced by ac magnetics can be used to correct the real-reluctance scans for lift-off variations allowing a very sensitive

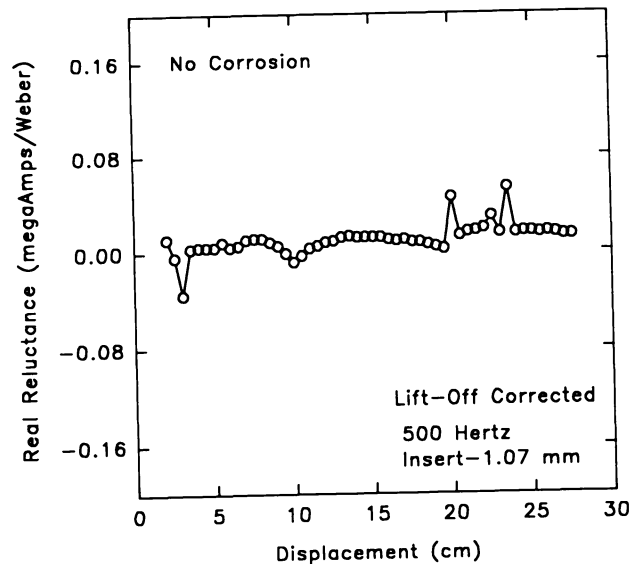


Fig 8. Result of removing lift-off variations from a real-reluctance scan of a control segment of a 55-gallon barrel.

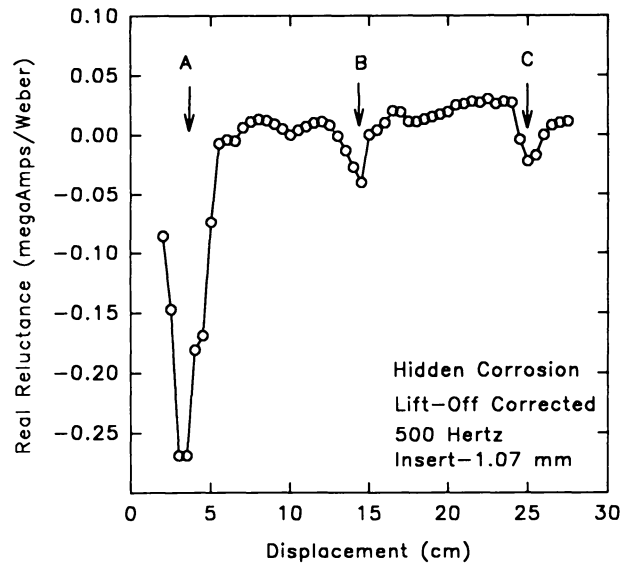


Fig. 9. Results of removing the lift-off variations from a real-reluctance scan of the etched segment of a 55-gallon barrel.

measurement of corrosion loss from the painted surfaces of 55-gallon barrels. Variations in steel quality were found to have little effect on the measurements.

Other problems in barrel inspection through ac magnetics require investigation. Among these are detection of loss on the stiffening rings on the barrel surfaces. This problem can probably be solved through design of the gap face of the bridge used in ac magnetics.

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